OPTIMAL PAVEMENT MAINTENANCE STRATEGIES FOR ADDIS ABABA CITY ROAD NETWORK USING HDM-4

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October 2018

Declaration

I certainly declare that this thesis entitled by "**Optimal Pavement Maintenance Strategies for Addis Ababa City Road Network, Analysis Using HDM4"** is my own work with referred materials explicitly cited.

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APPROVAL PAGE

This MSC thesis entitled with **"Optimal Pavement Maintenance Strategies for Addis Ababa City Road Network, Analyses Using HDM-4"** has been approved by the following examiners in partial fulfillment of the requirement for Degree of Master of Science in **Road and Transport Engineering.**

Date of defense: October 22, 2017

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Abstract

In developing countries like Ethiopia where the traffic growth and axle loading is growing, deterioration of highways is very fast. This increased traffic demands multilane highways with proper maintenance time to time. During the process of road network maintenance and rehabilitation, road authorities strive to select an optimum maintenance strategy from a number of alternatives. This selection may be obtained only through a realistic approach. An economically acceptable maintenance strategy may be selected among a number of maintenance alternatives. It can be done through the analysis of costs and benefits by comparing the various maintenance alternatives with the help of Highway Development and Management tool (HDM-4). This paper specifically addresses flexible pavement, including two principal arterial streets under the administration of Addis Ababa city Roads Authority. The roads include road from Gotera Interchange to Meskel Square and from Iran Embassy to Bisrate Gebriel. These roads are divided into different sections and the sections are in turn divided into segments each having 100m length. The Study involves data collection, data analysis and the selection of optimal maintenance strategy by using project analysis component of HDM-4 for the road sections under consideration. Four types of maintenance alternatives including Scheduled patching, overlay, thin lay and slurry seal were assigned. The optimum maintenance strategy has been selected by comparing Discounted Net Present Value, Road Deterioration (Roughness progression) and Emission by vehicle Report. The results of the analysis has shown that scheduled patching and overlay is the optimal maintenance alternative for both of the selected road networks. It is expected that the information contained in this paper would be a base line to develop optimal maintenance management strategy principal arterial streets in Ethiopia.

Key Words: *Defects, Maintenance alternatives*

Acknowledgements

My first Thanks would go to the Almighty God for his blessings throughout the advancement of this research. I have a special Thanks to Saint Virgin Marry, who gave me the strength to accomplish this study.

I have a heartfelt appreciation to my Advisor, Dr. Habtamu Melese, for his follow up and support up to the accomplishment of this study. Dr. Alemayehu Ambo, a humble and encouraging teacher of mine, who gave me support throughout the progress of this research, deserves a sincere veneration.

I am grateful to thank my whole families (my parents, my husband and my brother) for their heartfelt support till the end of this study. All my friends especially Hilina Demeke, Lecturer at Addis Ababa Institute of Technology, deserve to have my sincere gratitude.

Special appreciation should be given to Ato Tefera (WT Consult), the personnel at Addis Ababa Roads City Authority especially Engineer Abel, Ato Yared (Engineer Zewdie Eskindir Consult), UNICON consulting firm, Ethiopian Road Authority and to all governmental and private institutions who helped me for the advancement of this paper.

Contents

List of Tables

List of Figures

List of Abbreviations

AACRA	Addis Ababa City Roads Authority
AADT	Annual Average Daily Traffic
CI	Crack Index
DC	Deflection
ERA	Ethiopia Roads Authority
ESAL	Equivalent Single Axle Load
GDP	Gross Domestic Product
HDM-4	Highway Design and Management Tool
HMA	Hot Mix Asphalt
IQL	Information Quality Level
IRI	International Roughness Index
M&R	Maintenance and Rehabilitation
MT	Motorized Vehicles
NMT	Non-Motorized Vehicles
NPV	Net Present Value
PCI	Pavement Condition Index
RDI	Rut Depth Index
RI	Roughness Index
RUE	Road User Effects
SEE	Social and Environmental Effects
WE	Work Effects

CHAPTER ONE

INTRODUCTION

1.1. General

Transportation system is one of the most important factors affecting the national and public economy/development of any country. The better transportation system is the necessity for developing the nation and public economically (Khan, 2013). A well-developed road transport sector in developing countries is assumed to fuel up the growth process through a variety of activities of the development endeavors of a nation. Among these, creation of market access opportunities for agricultural products is the major one. In Ethiopia road transport is the dominant mode and accounts for 90 to 95 percent of motorized inter-urban freight and passenger movements (Ibrahim, 2011).

Construction of road network involves substantial investment and therefore proper maintenance of these assets is of paramount importance. It is found that the actual available maintenance expenditure amount is much less than what is required for urban roads. Preventive maintenance techniques should be scheduled to maximize safety, maintainability, and the cost-effectiveness of pavement preservation efforts. However, it is difficult for most users to establish the level of distress at which a particular maintenance treatment should be applied. Selection of the most appropriate maintenance treatment for a given distress type should consider several factors including type and extent of distress, climate, existing pavement type, cost of treatment, traffic type and volume, expected life, availability of qualified contractors, availability of quality materials, time of year, pavement noise, facility downtime (user delays), surface friction, anticipated level of service, and other project specific condition (Chopra, 2017).

1.2. Background

A road network system is perhaps one of the most important necessities for the economic development of any country, particularly developing countries. Many of developing countries, therefore, invest huge amount on road construction, while many others appreciate the necessity for huge investment in capital development of roads (Khan, 2013).

The continued extension and improvement of the road network does however create new and growing challenges in terms of an increasing maintenance burden. In order to sustain the benefits of the investments made in improving roads, there is a need to boost capacity in terms of providing adequate maintenance. After all, the expected benefits in terms of social and economic development will only materialize if the good transport infrastructure is maintained over time.

When road networks mature as a result of reaching the desired coverage of the rural population, more emphasis needs to be placed on the maintenance of already existing infrastructure assets. This implies that a growing portion of funding and technical and managerial capacity need to be allocated to protecting the investments made earlier in building the road network. In order to sustain the quality of the all-weather roads built to service rural areas, there is a need to mobilize political support for this change process to take place. Secondly, it involves significant changes within government institutions in charge of the road networks. A growing portion of total funding needs to be allocated to maintenance of existing roads together with the technical staff required to attend to road maintenance (Siddharth, 2012).

The developing countries have lost precious infrastructures worth billions of dollars through deterioration of their roads. If their government do not do much to prevent their roads, they will lose billions more. Large road networks, built at great expense have been under maintenance and more heavily used and abused than expected. If this continues, the deterioration of roads will increase rapidly as the old pavements crumble and the new ones outlive the initial period during which the effects of neglect are barely noticeable. The cost of restoring these deteriorated roads is going to be much higher than expected for the timely effective maintenance (Surajo, 2016).

The current maintenance practice in Ethiopia, specifically in Addis Ababa is to provide the maintenance and rehabilitation strategies based on subjective judgment and engineering experience (Temesgen, 2016). The principal causes for the deterioration of roads and ineffectiveness of different maintenance strategies often remain unevaluated due to nonavailability of objective data base required for the analysis of various activities, such as, design, construction, maintenance, etc. Consequently, the gap between the allocation and requirements has been accumulating over the years.

Road engineers, planners and managers are forced to make a more careful examination of cost effectiveness of various investment options due to the lack of financial resources. The development of scientific maintenance system will enable the engineers to project the requirement of funds to maintain the road network at a desired level of serviceability.

The HDM - 4 software tool developed by World Bank for global applications, can be effectively utilized for identifying optimum maintenance strategy for highway pavements. In this paper, optimum pavement maintenance strategy is arrived at by using HDM - 4 analyses for two selected roads in Addis Ababa city: including road from Gotera Interchange to Meskel Square and Iran Embassy to Bisrate Gebriel.

1.3. Statement of the problem

The existing maintenance trend of AACRA is deprived of techniques that are based on scientific prioritization methods which rely on economic feasibility and sustainable functionality. This lead to the provision of maintenance works based on subjective judgment and engineering experience. The Authority also uses common maintenance alternatives whose effectiveness is not analyzed based on scientific investigation. These has made maintenance trends not to be knowledge based. In order to come up with a solution for the above stated problems, the advancement of this research have been necessitated.

1.4. Objectives

1.4.1. General Objective

- To set economically feasible, functionally sound and environmentally safe pavement maintenance technique for the maintenance of the roads under the study.

1.4.2. Specific Objectives

- To recognize the available distress types on each section of the selected road way.
- To assign different maintenance alternatives for the respective distresses noticed on the roads under the study.
- To select the most economical, environmentally safe and functionally sound maintenance alternative by using HDM-4 software as an analysis tool.

1.5. Significance of the study

In countries which have budget constraints like Ethiopia, especial consideration should be given in addressing road maintenance applications economically with a sustainable future service. This study offers a scientific way of coming up with an economically, functionally and environmentally feasible maintenance alternatives for the road networks under consideration. This will save the budget allocated not to be spent on maintenance trends that are not scientifically investigated and which will result in a loss on the country's economy.

1.6. Research scope and limitation

The problems realized regarding maintenance timing and quality are extensive in Addis Ababa. Even though the problem is vast, it is difficult to address the whole roads in a single research.

Therefore emphasis is given to two sample principal arterial roads under the control of Addis Ababa City Road Authority which are envisaged to show the problem. It has been believed that the study on these two roads: road from Gotera Interchange to Meskel Square and from Iran Embassy to Bisrate Gebriel could represent defects and the maintenance problems and solutions to be given on the other roads in the city.

The limitations faced through the progress of undertaking this study include the following points:

- The unavailability of data required as an input to undergo the analysis: some default data of the software are taken without modification.
- The availability of some condition survey data which do not clearly show the degree of damage on the road under consideration.

CHAPTER TWO

LITRATURE REVIEW

2.1. Pavement Performance

Flexible pavements generally are referred to as asphaltic concrete pavement or bituminous surface treatment. They develop strength from the tight interlocking of crushed rocks with an asphalt material binding them together. This mixture deflects when loaded by traffic and exerts pressure on the subgrade. Consequently, both the pavement and the subgrade must be in good condition to avoid maintenance problems. To fulfill its purpose of construction a pavement should (Kadyali, 2012):

- Be structurally sound enough to withstand the stresses imposed on it.
- Be sufficiently thick to distribute the loads and stresses to a safe value on the subgrade.
- Provide a reasonably hard wearing surface, so that the abrading action of wheels (Pneumatic and iron-tired) does not damage the surface.
- Be dust-proof so that traffic safety is not impaired by reducing the visibility.
- Have a good riding quality and the surface should be impervious so that water does not get in to the lower layers of the pavement and the subgrade.
- The pavement should have long life and the cost of maintaining it annually should be low.

The factors influencing the performance of a pavement include (Sharad, 2015):

Traffic

Traffic is the most important factor influencing pavement performance. The performance of pavements is mostly influenced by the loading magnitude, configuration and the number of load repetitions by heavy vehicles. The damage caused per pass to a pavement by an axle is defined relative to the damage per pass of a standard axle load, which is defined as an 80 KN single axle load (E80).

Moisture (water)

Moisture can significantly weaken the support strength of natural gravel materials, especially the subgrade. Moisture can enter the pavement structure through cracks and holes in the surface, laterally through the subgrade, and from the underlying water table through capillary action. The result of moisture ingress is the lubrication of particles, loss of particle interlock and subsequent particle displacement resulting in pavement failure.

Subgrade

The subgrade is the underlying soil that supports the applied wheel loads. If the subgrade is too weak to support the wheel loads, the pavement will flex excessively which ultimately causes the pavement to fail.

Construction quality

Failure to obtain proper compaction, improper moisture conditions during construction, quality of materials, and accurate layer thickness (after compaction) all directly affect the performance of a pavement.

2.2. Pavement Deterioration

Pavement deterioration is the process by which distress (defects) develop in the pavement under the combined effects of traffic loading and environmental conditions (Sharad, 2015). Bituminous pavement deterioration generally takes place due to combined action of traffic, weather changes, drainage, environmental factors etc. (Khanna, 2014).

Rate of deterioration of bituminous pavement increases rapidly when water is retained in the void spaces of the bituminous pavement layers. Aging and oxidation of bituminous binder also leads to the deterioration of the bituminous surfacing (Surajo, 2016).

Types of pavement deterioration are grouped under four categories (Sharad, 2015).

- **Cracking**: incudes fatigue cracking, longitudinal cracking, and transverse cracking block cracking, slippage cracking, reflective cracking and edge cracking.
- **Surface deformation**: Surface distortions can be a traffic hazard. The basic types of surface deformation are rutting, corrugations, shoving, depressions and swell.
- **Disintegration**: The progressive breaking up of the pavement into small, loose pieces is called disintegration. If the integration is not repaired in its early stages, complete reconstruction of the pavement may be needed. The two most common types of disintegration are Potholes and Patches.
- **Surface defects:** they are related to problems in the surface layer. The most common types of surface distress are raveling, bleeding, polishing and delamination.

2.3. Common Distress Types in Addis Ababa Roads

The data received from AACRA show that out of the different types of pavement deterioration categories, the common defects available in Addis Ababa include fatigue cracking, rutting, pothole and raveling.

Rutting

This is the longitudinal deformation or depression of the pavement surface along the wheel path of heavy vehicles formed due to repeated applications of heavy load along the same wheel path resulting in cumulative non-recoverable or pavement deformation of the pavement layers including subgrade and one or more of the pavement layers (Surajo, 2016).

Fatigue Cracking

Fatigue cracking is commonly called alligator cracking. This is a series of interconnected cracks creating small, irregular shaped pieces of pavement. It is caused by failure of the surface layer or base due to repeated traffic loading (fatigue). Eventually the cracks lead to disintegration of the surface. The final result is potholes. Alligator cracking is usually associated with base or drainage problems. The cause of those distresses may rise from traffic conditions, construction quality, material type, environmental factors and other related reasons (Sharad, 2015).

Potholes

Potholes are small, bowl-shaped depressions in the pavement surface that penetrate all the way through the hot mix asphalt (HMA) layer down to the base course. They generally have a sharp edges and vertical sides near the top of the hole (Surajo, 2016). Most potholes would not occur if the root cause was repaired before development of the pothole (Sharad, 2015).

Raveling

Raveling is the loss of material from the pavement surface as a result of insufficient adhesion between the asphalt, cement and the aggregate. Raveling typically tends to occur on an older pavement that has already oxidized. Raveling can be accelerated by traffic and other environmental conditions (Surajo, 2016).

2.4. Pavement Maintenance

Maintenance of a road network involves a variety of operations, i.e., identification of deficiencies and planning, programming and scheduling for actual implementation in the field and monitoring. The essential objective should be to keep the road surface and appurtenances in good condition and to extend the life of the road assets to its design life. Broadly, the activities include identification of defects and the possible cause there off, determination of appropriate remedial measures; implement these in the field and monitoring of the results (Zulufqar, 2017).

Road maintenance policies should include key functional requirements that secure the quality of the existing rural road network from deteriorating, while new connectivity and up gradation works continue. Hence, there is a need to alter and refine the requirements at operational level, ensuring that economic and financial aspects as well as appropriate management arrangements are secured in order to actually carry out the necessary maintenance. This attempts to describe the functional requirements at operational level necessary for securing adequate maintenance of the road network.

Roads are rapid to become insurmountable to traffic until a point when they are no longer trafficable. The pace of deterioration largely depends on the quality of initial construction of the pavement and surface materials, and drainage measures, levels of traffic and weather conditions (Siddharth, 2012).

The maintenance trends of different developing countries show that there is a need for proper maintenance and rehabilitation practice. The principal causes for the deterioration of roads and ineffectiveness of different maintenance strategies often remain unevaluated due to nonavailability of objective data base required for the analysis of various activities, such as, design, construction, maintenance, etc. Consequently, the gap between the allocation and requirements has been accumulating over the years (Sudhakar, 2009).

Maintenance of highway is classified under the following categories (Zulufqar, 2017):

1. Routine Maintenance

Activities involved in routine maintenance are irrespective of the engineering characteristic of road and density of traffic carried by it. These are required to be carried out throughout the year.

The works to be attended under this category are as follows:

- Upkeep of carriageway
- Road sign maintenance
- Maintenance of berms/shoulder and subgrade
- Repair to pot holes, cracks and other minor defects
- Cleaning of drains and clearing of choked culverts
- Rectification of corrugations formed

2. Periodic Maintenance

It is nothing but periodic renewals of existing surface. In this type of maintenance a surfacing layer over the pavement at regular intervals of time so as to preserve the characteristics of the pavement and offset the wear and tear caused by traffic, weathering, etc. and thereby prolongs the life of pavement. The various types of periodic maintenance are as follows:-

- Surface dressing: helps to prevent pothole formation by providing a water proof seal and improves skid resistance with a thin layer of new stone chippings spread on the finished surface.
- Thin premix carpet: is a type of surfacing which has a life time of 4 to 10 years. For low rainfall areas a premix seal coat of sand and bitumen is used while areas with high rainfall use liquid seal coat with bitumen.
- Thin mix seal surfacing: a surface treatment in which an asphalt or seal coat pavement is sprayed with an asphalt binder and then covered with a single layer of aggregate. The type of binder that is typically used is an emulsion or a cutback.
- Improving drains: involves checking drainage lines at a regular base and providing the suitable maintenance treatment.
- Road surface marking: includes the regulation of parking and stoppings.

3. Special Repairs

The type, frequency and degree of maintenance of pavements can influence performance and time at which major rehabilitation such as overlay is required. Pavement rehabilitation is performed due to following two reasons (Zulufqar, 2017):

i. To correct existing distress and improve riding quality.
ii. To increase the structural capacity of pavement.

Critical elements of a successful pavement preservation program are (James, 2014):

- Selecting the roadway
- Determining the cause of the problem

- Identifying and applying the correct treatment(s)
- Determining the correct time to do the needed work
- Observing performance

There are different types of pavement preservation and not all are effective for the desired outcome. It is important to consider the intended purpose of the treatment before it is applied to the pavement. For example, preventive maintenance should be able to restore the function of the existing pavement and extend its service life, but not increase its structural capacity or strength.

An effective preservation programs addresses pavements while they are still in good condition. A cost-effective treatment in a timely manner will restore the pavement almost to its original condition. By doing so, the cumulative costs of such treatment are substantially less then reconstruction or major rehabilitation over the life of the pavement. In addition, the disruption of traffic is less for more frequent and minimal treatments in comparison to larger construction treatments (James, 2014).

Preventive maintenance should be applied to pavements in good condition having significant remaining service life. It applies cost-effective treatments to the surface or near-surface of structurally sound pavements. Examples include the following (James, 2014):

- Asphalt crack sealing: is sprayed along the crack path in order to remove the available crack areas.
- Chip sealing: effective treatment mechanism for linear block cracking, raveling and friction loss.
- Slurry or micro surfacing: a good treatment option to relieve raveling and friction loss.

- Thin and ultra-thin hot-mix asphalt (HMA) overlay: are structural overlays with thin thickness which can relive raveling, maintain grade and slope, minimize dust, etc.

Some preventive maintenance trends with their respective importance are illustrated below:

Slurry seal

Slurry seals are a mixture of asphalt emulsion, graded aggregates, mineral filler, water and other additives. The mixture is made and placed on a continuous basis using a travel paver (Slurry Surfacing Machine). The travel paver meters the mix components in a predetermined order into a pug mill. The typical mixing order is aggregate followed by cement, water, the additive and the emulsion. A slurry seal is used to (Caltrans.., 2003):

- Seal sound and oxidize pavements;
- Restore surface texture by providing a skid-resistant wearing surface;
- Improve waterproofing characteristics;
- Correct raveling;
- Provide a new surface where weight restrictions preclude the use of heavier overlays (e.g. bridge decks); and
- Provide a new surface where height restrictions are a problem (e.g., overcrossings).

A slurry seal should not be used to (Caltrans.., 2003):

- Correct surface profile;
- Fill potholes; and
- Alleviate cracking (with or without polymer modification).

A slurry surfacing does not add any structural capacity to an existing pavement; they are applied as a maintenance treatment to improve the functional characteristics of the pavement surface (Caltrans, 2003).

Thin lays

Thin lays are a suite of asphalt overlays that are developed for pavement preservation using proven pavement design principles. Early Thin lays have performed for more than ten years, double the life expectancy of other pavement preservation options (Asphalt, 2015).

Overlay is necessary when pavement section cross their maximum acceptable limits of deflection, rut depth, roughness and cracking and there is increase in traffic intensity. Overlay is generally laid when Characteristic Deflection (DC), Rut Depth Index (RDI), Crack Index (CI) and Roughness Index (RI) reach acceptable limits (Zulufqar, 2017).

2.5. Pavement Maintenance in Addis Ababa

In order to carry pavement rehabilitation and maintenance, the existing pavement condition must be evaluated. Such an evaluation usually involves the assessment of the existing pavement structural, functional, surface condition and safety evaluation using visual evaluation, none destructive testing, destructive testing. The ACCRA Road Management System Team is responsible for pavement evaluation. It is done on yearly bases using visual condition survey method in spread sheet which comprises: street number, street name, total length, road type, defect type, defected area detail (specific area, length, width, area and condition) (Temesgen Girmay, 2016). Sample spread sheet that is used by AACRA Road Asset Management Department is attached in Annex 1**.**

There is non-destructive test procedures for structural, functional and safety evaluation other than visual surface condition evaluation method which plays significant role in identifying major causes of distress for recommending the best option for maintenance and rehabilitation decisions.

The AACRA Road Asset Management Department develop schedule for the maintenance activities to be done either pouching or overlay which is already specified by road asset management department.

The condition survey data is summarized in this office based on PCI. Since the budget allocated by the Authority for the maintenance and rehabilitation is limited for maintenance and rehabilitation works, they prioritize based on severity grade to the road which is affected worst and currently they start using Matrix Method for maintenance and rehabilitation prioritization. Moreover they will focus on emergency works and other woks ordered by political pressure (Temesgen, 2016).

In AACRA, based on the distress types, they categorize maintenance methods either as overlay or patching. The thickness of overlay and the depth of patching are decided by the maintenance crew on site. There is no other specific maintenance treatment selection techniques practiced by the Authority (Temesgen, 2016).

2.6. Prioritization of Maintenance Techniques

To select the best maintenance option, it is necessary to list a variety of alternatives that may be feasible from an initial examination of the conditions. These possible alternatives can then be subjected to much more detailed examination of economic, design and construction factors. Other factors to consider include whether a long lasting or simply an economical short-term treatment is required. Once these questions are answered, a list of possible maintenance options could be selected for further study by finding those treatments that satisfy the above criteria. Treatments may include surface treatments, overlays, in-situ stabilization, or any other maintenance treatments (IJSR, 2013).

Time and/or traffic along with the pavement quality dictate when certain procedures must be done in order to maintain an appropriate and safe level of performance, starting with regular routine maintenance to complete reconstruction. (James, 2014).

There are different tools (software) that are used for prioritization of the different maintenance alternatives assigned for a specific study area. This particular study has used HDM-4 analysis tool to come up with the optimum maintenance technique for the areas under consideration.

2.6. Highway Development and Management Tool (HDM-4)

The HDM-4, developed by the World Bank, has been used for over two decades to combine technical and economic appraisals of road projects, to prepare road investment programs and to analyze road network strategies. The various versions of the models have been widely used in a number of countries, and have been instrumental in justifying increased road maintenance and rehabilitation budgets in many countries. The models have been used to investigate the economic viability of road projects in over 100 countries and to optimize economic benefits to road users under different levels of expenditures. As such, they provide advanced road investment analysis tools with broad-based applicability in diverse climates and conditions. (Kerali, 2006).

2.6.1. Functions and cycles

General

When considering the HDM-4 applications, it is convenient to view the highway management process in terms of the following functions (Robinson, 1988):

2.6.2. Functions

Planning

This involves an analysis of the road system as a whole, typically requiring the preparation of long term, or strategic, planning estimates of expenditure for road development and preservation under various budgetary and economic scenarios

Programming

This involves the preparation, under budget constraints, of multi-year road works and expenditure programmers in which those sections of the network likely to require maintenance, improvement, or new construction, as identified in a tactical planning exercise.

Preparation

This is the short-term planning stage where road schemes are packaged for implementation. At this stage, designs are refined and prepared in more detail; bills of quantities and detailed costing are made, together with work instructions and contracts.

Operations

These activities cover the on-going operation of a road agency. Decisions about the management of operations are made typically on a daily or weekly basis, including the scheduling of work. Following are the three main areas of analysis in HDM-4 which can be undertaken using the following applications (Morosiuk. 2006): Project analysis, Programme analysis and Strategy analysis:

- **Project Analysis**: Project analysis is concerned with the evaluation of one or more road projects or investment options. It includes the appraisal of M&R options for existing roads, widening or geometric improvement schemes, pavement upgrading, new road construction, etc.

  Economic benefits from road investments are then determined by comparing the total cost streams for various road works and construction alternatives against a base case (without project or do minimum) alternative, usually representing the minimum standard of routine maintenance. HDM-4 is designed to make comparative cost estimates and economic analyses of different investment options. It estimates the costs for a large number of alternatives year by-year for a user-defined analysis period. All future costs are discounted to the specified base year. In order to make these comparisons, detailed specifications of investment programs, design standards, and maintenance alternatives are needed, together with unit costs, projected traffic volumes, and environmental conditions. (HDM-4 Manual, Volume 1)

- **Programme Analysis**: Programme analysis is concerned with the preparation of work programs in which candidate investment options are identified and selected, subject to resource constraints. Road networks are analyzed section by section and estimates are produced of road works and expenditure requirements for each section over a funding period. Programme analysis may be used to prepare multiyear rolling work programs.

- **Network Strategy Analysis**: Strategic planning is concerned with the analysis of a chosen network as a whole. A typical application is the preparation of long range planning estimates of expenditure needs for road network development and maintenance under different budget scenarios. Estimates are produced for expenditure requirements for medium to long term periods of between 5 to 40 years.

2.6.2. Input Data of HDM-4

Road Network Data: The road network data collection in the field includes road Inventory data and road geometric details, structural evaluation (structural capacity), functional evaluation (pavement condition and riding quality) and evaluation of pavement material.

Fleet Vehicle Data: The vehicle fleet data includes the collection of basic vehicle characteristics, economic cost details of vehicles, traffic volume count & growth factors (Shah, 2016).

Maintenance and Rehabilitation Works Data: M&R strategy is a course of action to be taken over the analysis period in order to keep the road section in a good condition (IJIRSET, 2013). For a given feature type (that is, carriageway, shoulders, non-motorized traffic (NMT) lanes, miscellaneous and special), only one maintenance standard and/or improvement type will be effective in any analysis year (HDM-4 Manual, Volume 2). The following models are contained within HDM-4:

- Road Deterioration (RD): Predicts road deterioration for paved and unsealed roads;
- Works Effects (WE): Implements road works programs and determines works costs;

- Road User Effects (RUE): Determines costs of vehicle operation, road accidents and travel time; and
- Social and Environmental Effects (SEE): Determines effects of emissions and noise, and predicts numbers of road accidents and amounts of energy consumption.

Calibration

Calibration differs from input data since calibration is aimed at adjusting the model predictions. The degree of local calibration appropriate for HDM-4 is a choice that depends very much on the type of application and on the resources available to the user. For example, in planning applications, the absolute magnitude of the RUE and road construction costs need to match local costs closely because alternative capital projects with different traffic capacities or route lengths are evaluated on the comparison of the total road transport costs. In road maintenance programming, on the other hand, the sensitivity of RUE to road conditions, particularly roughness, and all the road deterioration and maintenance predictions are the most important aspects. There are three levels of calibration for HDM-4, which involves low, moderate and major levels of effort and resources, as follows:

Level 1 - Basic Application

In order to run HDM-4 it is always necessary to undertake at least a Level 1 calibration; this can be viewed as a set-up investment for the model. Once this has been done, it generally does not need to be repeated for most of the input data files during future applications in the same country since many data items and most model parameters are relatively stable over time. A Level 1 calibration is largely based on secondary sources; that is, it is a desk study.

Level 2 – Calibration

A Level 2 calibration uses direct measurements of local conditions to verify and adjust the predictive capability of the model. It requires a higher degree of data collection and precision than in a Level 1 calibration, and extends the scope. For the economic analysis, it ties cost data more closely to observed cost and price levels through data collection surveys. With Level 2 calibrations, more detailed input data are also collected than with Level 1.

Level 3 – Adaptation

A Level 3 calibration is generally comprised of two components:

- Improved data collection
- Fundamental research

Some data items can be estimated with reasonable accuracy using short-term counts, for example the hourly distribution of traffic volume, but the reliability is greatly enhanced by collecting data over more sites over a longer period. Such work requires a major commitment to good quality, well-structured field research and statistical analysis over a period of several years. Pavement deterioration research is a particularly long-term endeavor, typically requiring a minimum of 5 years (HDM-4 Manual, Volume 5).

CHAPTER THREE
METHODOLOGY

3.1. Research Area

The area under this study consists of two roads in Addis Ababa city: the road from Bisrate Gebriel (Tele Square) to Iran Embassy (Ring road) and the road from Meskel Square to Gotera Interchange covering a total length of 1.3Km and 3.3Km respectively. The reason behind the selection of these two roads lies on the availability of most of the required data for the analysis. The property of the roads has been studied in detail by dividing the whole covering length into different sections which in turn are divided into small segments each having 100m length. One direction of the road is considered as one network, since the roughness data show a different roughness index value for the two directions of the carriageway. There is a varying altitude for each segment of both roads. But generally the altitude increases from 2319.33m at Bisrate Gebriel to 2330.62m at Iran Embassy and it increases from 2187m at Meskel Square to 2268 m at Gotera Interchange.

3.2. Research Design

In order to address the research problem, different phases were followed. The collection of data which are necessary for the analysis was executed as a first phase. After having the important data at hand, analysis using HDM-4 was done. Since there are several analysis output groups offered by HDM-4, the selection of focus groups was undertaken. The focus group includes Road Deterioration and Works Effect Report, Cost Streams report and Environmental effect report. The contemporary maintenance selection and application trends of AACRA are presented in a descriptive mode.

3.3. Scope and Limitation

This study mainly has focused on road networks under the administration of AACRA, two of which are taken into consideration specifically. The limitations faced in the progress of this research are basically the unavailability of properly documented data and the existence of data which doesn't represent the exact required characteristic information of the roads.

3.4. Data collection

The data sets which are necessary for the study have been taken from AACRA and from different consulting firms. Documents related to road condition which includes international roughness index (IRI) data and condition survey data were taken from AACRA. For other documents describing pavement design, geometric design, vehicle characteristics and AADT, consultants were used as data sources. Summarized description of the data sources and documents is clearly shown in the Table below.

Table1: Data types and their sources

No.	Data Type	Data Source
1	Condition survey data	AACRA
2	Engineering reports	United consult and Engineer Zewdie Eskindir Consult
3	Vehicle characteristics	WT Consultant
4	Economic and financial costs	AACRA and WT Consult
5	Traffic data	United consult and Engineer Zewdie Eskindir consult
6	Climate data	Ethiopian Metrology Agency

3.5. HDM- 4 Input Data

The extent of how detail the required input data are depends up on the type of the analysis used. From the three types of analysis strategies discussed in chapter two, project analyses is used for this study which require input data to be at a detailed level. Project analysis needs quantified data while program analysis and strategy analysis use data which may be expressed qualitatively. In order to clarify this difference a concept called Information Quality Level is used. Project level analysis data is specified in terms of measured defects (IQL-II), whereas the specification for strategy and Programme analyses can be more generic (IQL-III). For example; for project level analysis, road roughness would be specified in terms of the IRI value (m/km); but for strategy and Programme analyses, roughness could be specified as good, fair or poor. The relationship between IQL-II and IQL-III level data is user-defined in the HDM Configuration depending on road class, pavement surface type and traffic class. (HDM-4 Manual, Volume 1). The Information Quality Levels and their specific property as proposed by the World Bank are clearly shown in Table 2 below.

Table 2: World Bank Proposals for Application of Information Quality Levels (IQL)

Information Quality Level	Short Description	Applications	Data Collection
IQL I	Most detailed and comprehensive	- Research - Operations - Advance design - Diagnosis	Short to limited lengths or isolated samples using specialized equipment, slow except for advanced automation.
IQL II	Detailed	- Preparation (design) - Advanced programming - Advanced planning	Limited lengths using semi-automated methods, or full coverage using advanced automation at high speed.
IQL III	Summary details with categorization of values	- Programming - Planning - Basic design	Full sample using high speed, low accuracy semi-automated methods, or sample at slow speed, or processed from other data.
IQL IV	Only summary	- Sector/network statistics - Low volume road design - Sample planning and programming	Manual or semi-automated methods processed or estimated.

/Source: Kamal, 2011/

The basic data managers of HDM-4 and their respective data requirement will be discussed in the next section.

3.5.1. Road Network Data

The road network data includes both functional condition and structural condition. The functional data includes IRI in m/km, rut depth in mm, type and extent of distress, etc. (Pavan, 2016). Structural number of the pavement and CBR of the subgrade are considered as structural condition data. It allows users to define different networks and sub-networks, and to define road sections, which is the fundamental unit of analysis. The data entities supported within the road network are (HDM-4 Manual, Volume 1):

- **Sections**: Lengths of road over which physical characteristics are reasonably constant.
- **Links:** Comprise one or more sections over which traffic is reasonably constant. This is provided for purposes of compatibility of the network referencing system with existing pavement management systems.
- **Nodes:** Intersections which connect links or other points at which there is a significant change in traffic, carriageway characteristics, or administrative boundaries.

Generally the road network data is categorized into section definition, geometric, pavement and condition data. Data including Section definition, geometry and pavement were collected from consultants while the source for pavement condition data was AACRA. Table 3 below shows a summary of road network stretches and traffic data.

Table 3: List of road networks and traffic details

Name of the Road network	Length(km)	No of sections	Sections ID	No. of segments	CBR	AADT
Gotera to Meskel Square	3.3	2	Section 1	17	2	34,873
			Section 2	8		
Meskel Square to Gotera	3.3	2	Section 1	17	2	31,887
Iran Embassy to Bisrate Gebriel	1.3	1	Section 1	15	2	18,551
Bisrate Gebriel to Iran Embassy	1.3	1	Section 1	15	2	20,345

/Source: AACRA, 2016/

Table 4: Condition survey data for distress

Name of the Road network	Carriage way width(m)	Raveling (%)	No. of Potholes per km
Gotera to Meskel Square	**7**	**0.36**	**13**
Meskel Square to Gotera	**7**	**0.36**	**13**
Iran Embassy to Bisrate Gebriel	**10**	**1**	**10**
Bisrate Gebriel to Iran Embassy	**10**	**1**	**10**

/Source: AACRA, 2016/

3.5.2. Vehicle Fleet Data

This section includes vehicle characteristics, economic unit costs, vehicle composition and traffic growth rates. The vehicle types considered for this study categorized into different classes: all of them being motorized vehicles. The following table shows summary of vehicle types, characteristics and economic unit cost data of representative vehicles: the data being basic constituents of vehicle fleet data under HDM-4.

Table 5: Vehicle Characteristics and Economic Unit costs

Physical characteristics	Car	Large car	Small bus	Large bus	Small truck	Medium truck	Large truck	Truck & trailer
Operating weight (kg)	1200	1600	5200	9000	5500	13000	22000	28000
Axle per vehicle(No.)	2	2	2	2	2	2	3	5
Number of wheels	4	4	4	6	6	6	10	18/26
Tires per vehicle (No.)	4	4	4	6	4	6	10	18
Basic number of recaps	1	1.3	1.3	1.3	2	2	1.3	2
Utilization								
Annual run (km)	20000	40000	50000	60000	50000	60000	65000	65000
Annual hours	500	900	1600	1800	1600	1800	2100	2100
Average service life (year)	12	12	15	15	12	15	15	15
Private use (%)	85	20	15	0	0	0	0	0
Passenger occupancy (No)	3	3	20	45	0	0	0	0
Work related trips (%)	15	80	85	100	100	100	100	100
Economic Cost								
One new vehicle (birr) (*1000)	1378	2387	1874	2650	1860	3150	3400	4281.727
One tire (birr)	2200	3500	8500	15800	8100	15800	16000	17700
One liter fuel (birr)	15.00	15.00	14.40	14.40	14.40	14.40	14.40	14.40
One liter lubricant (birr)	90.16	90.16	80.23	80.23	80.23	80.23	80.23	80.23
Hourly maintenance cost(birr)	37.76	38.76	37.52	43.95	30.99	36.07	41.64	43.19
Hourly crew cost(birr)	0	0	57.14	53.84	33.94	39.09	59.55	80.91

/Source: WT Consult, 2016/

The consultants have studied the vehicle composition and annual growth rate for the representative vehicles on each of the road networks. Table 6 and table 7 show this data for the network from Bisrate Gebriel to Iran Embassy and Gotera Interchange to Meskel Square respectively.

Table 6: Vehicle composition and annual growth rate (%)

Vehicle type	Vehicular Composition (%)		Annual growth rate (%)
	Bisrate Gebriel to Iran Embassy	Iran Embassy to Bisrate Gebriel	
Small Cars	86.19	87.1	6
Mini bus	8.08	8.3	5
Large Bus	0.55	0.34	4
Small Truck	2.56	2.33	6
Medium & heavy Truck	1.98	1.73	4
Trucks &Trailers	0.64	0.2	4

/Source: United Consult, 2008/

Table 7: Vehicle composition and annual growth rate (%)

Vehicle type	Vehicular Composition (%)		Annual growth rate (%)
	Gotera Interchange to Meskel Square	Meskel Square to Gotera Interchange	
Car	94.02	93.01	8.67
Medium vehicle	5.46	6.34	8.67
Light vehicle	0.28	0.31	8.67
Heavy vehicle	0.12	0.23	8.67
Articulated Vehicle	0.12	0.11	8.67

/Source: Engineer Zewdie Eskindir Consult, 2004/

According to Table 7 there are four category vehicle types. Their definitions according to Engineer Zewdie Eskindir Consult will be given as follows.

- **Cars**

  Cars are motor cars with seating capacity of not more than 12 persons (including the driver) this class has 2 axles, 4 tires, less than 3mt length and gross vehicle weight of less than 3.5T. It includes utility, minibus and 4WD.

- **Light**

  Light drivers vehicles includes, bus, regular passenger service Coaches with more than 50 seats and two axle trucks, 6tires and length of 3m- 7.5m, with gross vehicle weight between 3.5T – 12T.

- **Heavy**

  Heavy vehicle of this category includes all heavy goods vehicles with 4axles, 14tyres, and length of greater than 7.5m and gross vehicle weight of greater than 12T.

- **Articulated**

  This includes semi-trailer category and heavy goods vehicle covering all articulated horse and trailer combination vehicles with 5 or more axles.

3.5.3. Maintenance and Rehabilitation Works Data

Maintenance Standards define the maintenance works required to maintain the road network at the target level. Each Maintenance Standard consists of a set of one or more Works Items. Each Works Item is defined in terms of the road surface class to which it applies, an intervention level, an operation type (e.g. reseal, overlay, etc.), and the resultant effect on the pavement. (HDM-4 Manual, Volume 3)

A) Gotera Interchange to Meskel Square

The dominant types of distresses that were noticed on the road network from Gotera Interchange to Meskel Square are pothole formations and raveling. Three maintenance alternatives, additional to the base option, are set for the road from Gotera Interchange to Meskel Square.

i. Base option

The existing maintenance trend which was undertaken by AACRA Maintenance Department to address the defects on the road is overlay and patching. The list of roads which need emergency maintenance treatments are shortlisted and transferred to Road Asset Management department.

ii. Alternative one

Slurry seal and patching is the other maintenance technique which is considered as a first alternative to address the distresses. Slurry seal is a mix Asphalt Emulsion, Water, Aggregate, Mineral Filler and Additives. A slurry surfacing does not add any structural capacity to an existing pavement; it is applied as a maintenance treatment to improve the functional characteristics of the pavement surface.

iii. Alternative Two

Thin lay is a type of maintenance which can address different types of distress by providing the pavement functional and structural qualities. It is designed to address all of the following important Preservation needs:

- Correct Surface distress;
- Seal the existing surface;
- Improve Serviceability ;

- Provide long life; and
- Extend structural life.

iv. **/Alternative three**

The other alternative that is assigned to remove the distress is reconstructing the road. Since the design life of the road will end after 6 years, checking the effectiveness of reconstruction is taken as one of the alternatives. Reconstruction involves the construction of a pavement, starting from subgrade.

v. **Alternative Four**

Applying overlay and patching at a scheduled base is the other maintenance alternative which is set for this road network. The overlay is designed to serve for six years: till the end of design life of the road. Patching will be held at a yearly base.

B) Iran Embassy to Bisrate Gebriel

Defects that are dominant on the road from Iran Embassy to Bisrate Gebriel are pothole formation and rutting. Two Alternatives are set for this road network. The base option and the other assigned alternatives with their definition and characteristics are explained in the following section.

i. **Base Option**

The maintenance technique that was applied by AACRA maintenance department for the distresses was only patching.

ii. **Alternative one**

The first Alternative that was assigned to address the distresses is patching and thin lay: thin lay providing functional and structural support to the pavement. With limited funding and aging roads, agencies need cost-effective, long lasting pavement preservation techniques. Thin lays are a suite of asphalt overlays that are developed for pavement preservation using proven pavement design principles. Early Thin lays have been performed for more than ten years, double the life expectancy of other pavement preservation options. (Asphalt, 2015)

iii. **Alternative two**

Overlay and patching is provided as the first alternative to address the defects on the road. Applying patching will seal the potholes while overlay will renew the pavement surface by providing functional and structural support.

iv. **Alternative Three**

The application of patching operation in a scheduled manner is taken as a third maintenance Alternative. The operation is scheduled to be undertaken at yearly schedule.

A summary of the proposed maintenance alternatives with their respective economic cost is given in Table 8 below.

Table 8: Cost of Maintenance works

No.	Type of maintenance work	Economic Cost (birr/sq.m)
1	Patching	432
2	Overlay	567
3	Slurry seal	107
4	Thin lay	331
5	Reconstruction	797

/Source: World Bank, 2001/

3.6. Data Analysis

Project analysis is used to compare the proposed maintenance alternatives for the two road networks. The assigned maintenance alternatives, road network data, vehicle fleet data and traffic data work as an input for the analysis. There are two methods which are used in the analysis.

3.6.1. Analysis by section

This is analysis type which analyses each of the road sections that make up the project individually. Several alternatives can be defined for each section with one alternative designated as the **base case** against which all the other alternatives will be compared. Economic indicators (which include, NPV, EIRR, BCR and FYB) were calculated for each section alternative. The definition of these terms is illustrated below.

- Net Present Values (NPV): the difference between the present value of cash outflows and cash inflows.

- Economic Internal Rate of Return (EIRR): the discount rate at which the Net Present value will be zero.
- Benefit Cost Ratio (BCR): the ratio between the benefits that will be gained from the project to costs.
- First Year Rate of Return (FYRR): shows how early can the project returns its investment back to the owner.

3.6.2. Analysis by project

This analysis type analyses road sections together as a package by considering project alternatives as the basic unit for performing economic analysis. First, the annual costs and benefits are summed over all the section alternatives within each project alternative to give yearly totals. Economic indicators were then calculated for each project alternative by comparison against a **base case** alternative (HDM-4, Volume 2).

Analysis by section was used for this study in order to understand the effect of each assigned maintenance alternative on the segments. After having a look at the outputs individually, the results will be summed up to understand the overall effect of the alternatives.

The results of analyses to be performed within HDM-4 have been grouped as follows (HDM-4 Manual, Volume 2):

- Deterioration/works effects
- Road user effects
- Environmental effects
- Energy use
- Cost streams
- Others

- User-definable reports

In this study; deterioration/works effects, environmental effects and cost streams are used in order to prioritize the optimum maintenance alternative for the road networks. The reason behind the selection of these output groups was data unavailability which was basic to other output groups as an input. The summary of the concerned analysis result groups will be discussed in the following section.

Pavement deterioration and road works

- Summary of annual pavement condition
- Quantities of road works
- Details of annual road work costs
- Schedule of road works

Environmental effects

a) Vehicle emissions: the objective of modeling vehicle emissions is to assess the effects, in terms of pollutant quantities, of changes in road characteristics, traffic congestion, and vehicle technology. As maintenance alternatives are changed the emission characteristics of the vehicles will also vary.

   The model predicts the different components of vehicle exhaust emissions as a function of fuel consumption. Fuel consumption is a function of vehicle speed, which in turn depends on road characteristics and the characteristics of the vehicle itself. Thus, it is possible to analyze the change in emissions effects as a result of implementing different road maintenance and improvement options, or the implications of major changes to the vehicle fleet (for example, due to improved vehicle technology). The different components of emissions modelled are hydrocarbon, carbon monoxide, nitrous oxide, sulphur dioxide, carbon dioxide, particulates and lead (HDM-4 Manual, Volume 4).

b) Energy consumption

The energy used by motorized vehicles is generally from non-renewable sources. The following resource components, used in vehicle operation are included in the energy balance analysis (HDM-4 Manual, Volume 4):

- Fuel consumption
- Lubricating oil consumption
- Tyre wear
- Vehicle parts consumption

Economic analysis results (HDM-4 Manual, Volume 1):

- Annual cost streams;
- Discounted cash flows;
- Net Present Values (NPV);
- Economic Internal Rate of Return (EIRR);
- Benefit Cost Ratio (BCR); and
- First Year Rate of Return (FYRR).

Out of the above list of economic analysis components Net present Value is taken as a comparison tool, since it has a fixed way of expressing the results than other economic comparison elements. In NPV negative values are loss, zero values are neither loss nor profit while positive values are always profit indicators. IRR bases its comparison based on the pre settled profit margin of the owner.

CHAPTER FOUR

RESULTS & DISCUSSIONS

Out of several different analysis output groups provided by HDM-4, a focus was given to the Deterioration and Road works effects, Economic analysis summary and Vehicle emission report. Under Economic analysis summary, the summary of total Discounted Net Present value report of each segment was considered. The comparison between the different maintenance alternatives provided in this study was done by considering these groups of analysis results as an input.

Summary of the results will be discussed in the following section.

4.1. Net Present Value

This report shows discounted Net Present Values for each segment of the road networks. Net present value is the difference between total discounted benefits and total discounted costs at the opportunity cost of capital. The higher the Net Present Value the more Profitable the maintenance alternative is. The results for the road networks will be presented as follows.

Gotera Interchange to Meskel Square

Section One

This section has seventeen segments: each with a length of 100m. Four different maintenance alternatives were set for this network. Table 9 illustrates a summarized report of total discounted Net Present Values of these alternatives.

Table 9: Net Present Values

Segment No	Base option	Alternative 1	Alternative 2	Alternative 3	Alternative 4
1	0	15.823	0.238	-15.222	6.32
2	0	12.799	-2.79	-6.474	12.434
3	0	-33.526	0.245	-18.28	1.588
4	0	-46.721	0.27	-29.334	-18.762
5	0	-39.86	0.257	-23.605	-7.778
6	0	10.124	-5.461	-6.478	9.78
7	0	-51.441	0.233	-33.643	-29.865
8	0	9.648	-5.937	-6.479	9.308
9	0	10.794	-4.791	-6.478	10.445
10	0	10.659	-4.926	-6.478	10.31
11	0	8.805	-6.78	-9.281	8.478
12	0	13.166	-2.468	-6.482	12.794
13	0	11.162	-4.423	-6.477	10.81
14	0	10.963	-4.622	-6.478	23.412
15	0	9.367	-6.218	-6.479	9.029
16	0	15.649	-1.148	-11.117	12.215
17	0	-49.489	0.275	-31.691	-23.549
Sum	0	-82.078	-48.046	-230.476	56.969

Note: Currency: Birr (millions)

Discount Rate: 10.3% (Source, National Bank of Ethiopia)

As illustrated above, the existing maintenance trend for this road network (overlay and patching) shows a zero NPV value for all of the segments under consideration. Alternative 1 (slurry seal and patching) has resulted positive value for ten segments, while the other five segments show a high negative NPV: resulting a negative sum. Only six segments show positive NPV for alternative two (thin lay and patching), the others having a negative value. Therefore, the sum for this alternative is also negative. Reconstruction of the pavement, Alternative 3, has resulted negative NPV values for all of the segments under this section. This stringently shows that using this maintenance alternative will result in a high loss. Differently Alternative 4 has brought a total positive sum, with four segments having a negative value, the others being positive. Therefore Alternative 4 (scheduled patching and overlay) is the one with high and positive NPV when compared to the other given alternatives.

Section Two

Only three segments are considered with in this section since it was difficult to get the complete data set. Similar to the above network four types of maintenance alternatives were considered.

Table 10 below shows a list of NPVs for the maintenance alternatives under consideration.

Table 10: Net Present Values

Segment no	Base option	Alternative 1	Alternative 2	Alternative 3	Alternative 4
1	0	11.585	-2.745	-5.932	11.231
2	0	-40.653	0.259	-24.27	-9.025
3	0	-42.99	0.29	-27.63	-14.546
Sum	0	-72.058	-2.196	-57.832	-12.34

Note: Currency: Birr (millions)

Discount Rate: 10.3% (Source, National Bank of Ethiopia)

The existing maintenance trend has resulted in zero value. One of the three segments has shown positive value and the other two has resulted in negative NPVs for Alternative one. This has brought a negative sum of NPV. Two positive and one negative value has been shown by the segments for alternative two: thin lay and patching. Reconstruction of the road: alternative three has resulted in a negative value for all segments under concern. Similar to Alternative one, Alternative four has given one negative and two positive values, providing a total negative sum. The different incident here is that all the alternatives have resulted in a negative NPV sum. There for the only option for selecting the better maintenance alternative will be picking out the alternative with the least negative value. Consequently Alternative two will be an alternative with high NPV.

Meskel Square to Gotera Interchange

Section One

Four different maintenance alternatives were set for this network with seventeen different segments. A summary of Net Present Values are presented in Table 11 below.

Table 11: Net Present Values

Segment no	Base option	Alternative 1	Alternative 2	Alternative 3	Alternative 4
1	0	13.817	-0.647	-8.276	12.116
2	0	14.238	-0.227	-8.5	12.019
3	0	12.764	-1.701	-5.943	12.372
4	0	11.912	-2.553	-5.943	11.531
5	0	14.753	0.289	-16.453	2.291
6	0	12.142	-2.322	-5.943	11.758
7	0	9.871	-4.597	-8.373	9.511
8	0	102.302	-41.248	-88.902	99.14
9	0	10.055	-4.41	-8.407	9.693
10	0	12.638	-1.827	-7.688	11.967
11	0	12.915	-1.549	-5.943	12.51
12	0	7.418	-7.046	-7.773	7.087
13	0	8.034	-6.43	-7.992	7.693
14	0	12.398	-2.067	-9.131	12.036
15	0	11.712	-2.753	-5.944	11.333
16	0	14.748	0.283	-12.782	8.32
17	0	9.815	-4.649	-8.364	9.456
Sum	0	2 91.532	-83.454	-222.357	260.833

Note: Currency: Birr (millions)

Discount Rate: 10.3% (Source, National Bank of Ethiopia)

According to Table 11 above the base option has shown a zero NPV once again. Unlike to the other direction of the road network, Alternative 1 has resulted in a positive value for all of the segments under consideration: resulting in a positive total sum. Alternative 2 has given a low positive value only for two segments: the other segments being negative. As a result, a negative sum of NPV has been resulted. Similar to the above road network, alternative 3 has shown negative value for all of the segments under the road network. Alternative 4 has brought about a high positive sum than the other alternatives, with each segment having a positive value.

Section Two

The alternatives provided for this section are similar to section one. The table below illustrates the discounted Net Present Value of the different maintenance alternatives.

Table 12: Net Present Values

Segment No	Base option	Alternative 1	Alternative 2	Alternative 3	Alternative 4
1	0	7.95	-6.515	-8.2	7.616
2	0	9.003	-5.462	-8.497	8.658
3	0	8.28	8.28	8.28	7.942
4	0	8.65	-5.814	-8.416	8.307
5	0	8.898	-5.569	-8.473	8.55
6	0	9.993	-4.471	-5.941	9.637
7	0	8.833	-5.631	-8.459	8.488
8	0	-31.175	0.291	-17.593	1.462
Sum	0	30.432	-24.891	-57.299	60.66

Note: Currency: Birr (millions)

Discount Rate: 10.3% (Source, National Bank of Ethiopia)

Similar to the other sections, the base option has resulted in a zero value for this one. Alternative 1 has given a positive value for all segments except one segment: finally giving a positive sum. Only two segments show a small positive value to Alternative 2 while the others are having negative value. Consequently, a negative sum has been resulted. A negative value of NPV indicates that applying the alternative will bring about a loss. Alternative 3 has shown a negative value for all segments. All segments have shown a positive NPV for Alternative 4. Subsequently Alternative 4 has shown the higher NPV while Alternative one has resulted in the second higher value.

Iran Embassy to Bisrate Gebriel

The distresses noticed on this network were pothole and Raveling. Three maintenance alternatives additional to the base option are assigned to address these distresses. A list of the maintenance alternatives with their respective NPV is presented in Table 13 below**.**

Table 13: Net Present Values

Segment no	Base option	Alternative 1	Alternative 2	Alternative 3
1	0	6.938	7.762	0.15
2	0	6.5	6.484	0.361
3	0	7.825	11.478	-0.002
4	0	7.734	9.989	0
5	0	4.245	1.793	1.476
6	0	4.331	1.954	1.447
7	0	7.825	11.478	-0.002
8	0	4.821	2.899	1.241
9	0	7.449	8.927	0.045
10	0	4.765	2.459	1.322
11	0	4.888	3.035	1.203
12	0	4.065	1.457	1.539
13	0	5.927	4.154	1.357
14	0	7.734	9.989	0
15	0	6.782	6.558	0.642
Sum	0	91.829	90.416	10.779

Note: Currency: Birr (millions)
Discount Rate: 10.3% (Source, National Bank of Ethiopia)

The base option has a zero value as the other sections. Unlike to the road network from Gotera Interchange to Meskel Square, all the alternatives show a positive total sum. Alternative 1 has resulted in the highest NPV sum while Alternative 2 and 3 comes next respectively. These positive results indicate that it is profitable to apply these alternatives as a maintenance solution for the road network under consideration.

Bisrate Gebriel to Iran Embassy

Similar to the other direction of the road network, three maintenance alternatives additional to the base option were considered. These include: thin lay and patching, overlay & patching and scheduled patching. The list of maintenance alternatives with their respective NPV is illustrated in Table 14 below.

Table 14: Net Present Values

Segment no	Base option	Alternative 1	Alternative 2	Alternative 3
1	0	5.385	3.143	1.663
2	0	6.301	9.055	-0.003
3	0	6.151	4.808	1.088
4	0	7.159	8.544	0.164
5	0	6.983	7.896	0.267
6	0	5.949	4.688	1.093
7	0	5.233	2.746	1.85
8	0	7.438	10.289	0.009
9	0	5.199	6.763	-0.002
10	0	7.466	11.297	-0.003
11	0	7.459	10.28	-0.003
12	0	7.467	11.297	-0.003
13	0	6.745	7.093	0.429
14	0	7.464	11.297	-0.003
15	0	1.49	1.283	0.241
Sum	0	93.889	110.479	6.787

Note: Currency: Birr (millions)

Discount Rate: 10.3% (Source, National Bank of Ethiopia)

A zero sum has been resulted in the case of base option. Alternative 1 and 2 has resulted in a higher NPV with all of the segments resulting in a positive NPV. Six segments have shown small negative values towards alternative three. But, the overall sum is positive. Consequently applying one of these three maintenance alternatives will be profitable; Alternative 2 being the most profitable.

4.2. Pavement Deterioration Report

Road deterioration illustrates the condition of the road at the end of each year till the end of design period of the road network. The condition at the end of the year was expressed in terms of roughness of the road, which is quantified in terms of International roughness index (IRI). The higher the roughness index the rougher the road is: which implies a difficulty to ride. The analysis results of different sections will be illustrated below.

Gotera Interchange to Meskel Square

Section one

Figure 1 below illustrates the roughness progression under different alternatives.

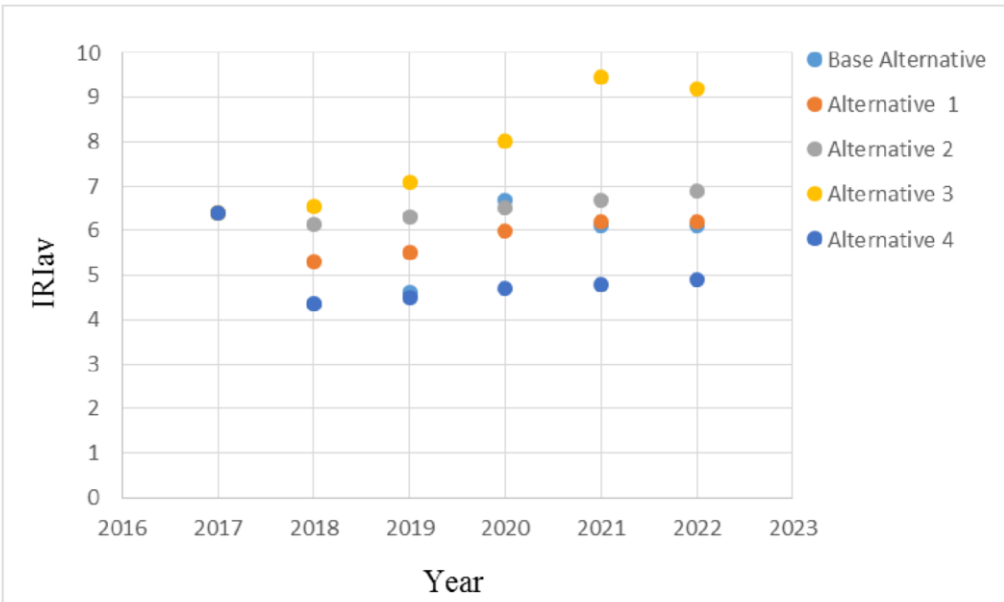

Figure 1: Roughness progression under different alternatives

According to Figure 2 above, Alternative 4 has resulted in a lower IRI value. The base option, Alternative 1, 2 and 3 have produced higher IRI value respectively. Alternative 3 (reconstruction) has resulted the highest IRI value when compared to the other three alternatives. Accordingly, Alternative 4 will keep the road fit its functional quality.

Section two

Figure 2 below illustrates the roughness progression under different alternatives.

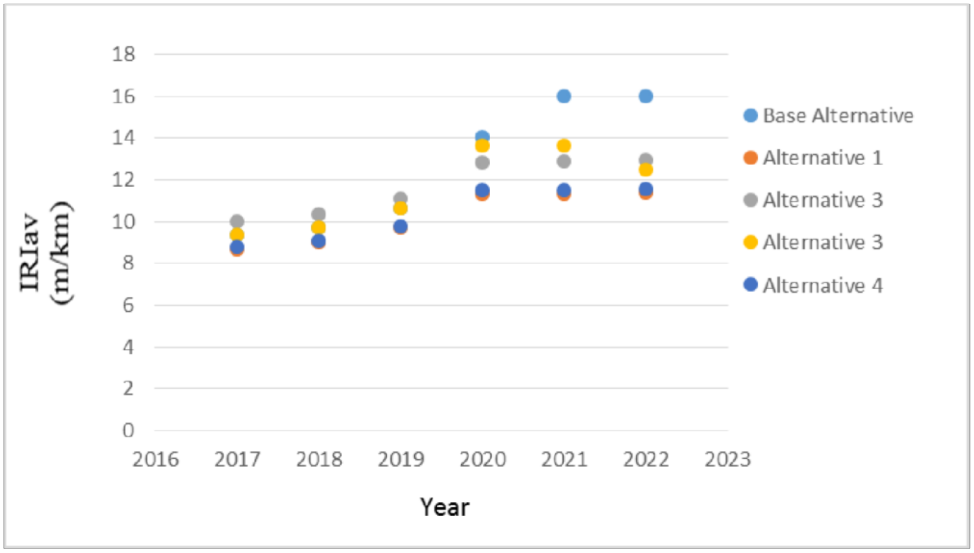

Figure 2: Roughness progression of different alternatives

From Figure 3 it can be understood that Alternative 1 and 4 have resulted in close and lower roughness values: Alternative 1 being the least. The base alternative has resulted in the maximum IRI value. The higher the roughness condition the rougher the road would be.

Meskel Square to Gotera Interchange

Section One

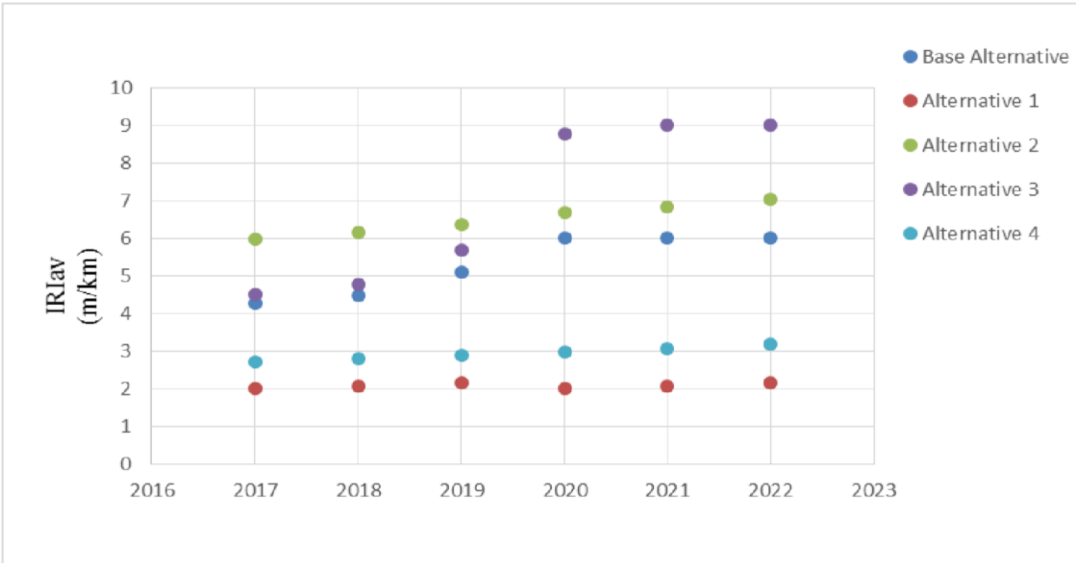

Figure 3: Roughness progression of different alternatives

It can clearly be understood from Fig 4 that Alternative 1 has resulted in the lowest IRI progression, Alternative 4 being the second alternative with lower roughness progression. The base alternative, Alternative 2 and 3 has resulted in higher IRI values respectively. Consequently, Alternative 1 is found to keep the road in a safe riding condition.

Section Two

Figure 4: Roughness progression of different alternatives

The results under section two have been found to be similar with Section one: Alternatives 1 and four resulting in lower IRI value. Since the results show that Alternative 4 will have the least roughness progression using this maintenance alternative will preserve the road fit its functional requirement. Alternative 3 (Reconstruction of the road) has shown the maximum roughness progression: thus leaving the road with rough riding condition. Therefore, Alternative 4 is recommended.

According to the above results, Alternative 4 will give the road lower roughness progression value. The maintenance action planned in this alternative is scheduled patching and overlay. The existing maintenance trend followed by AACRA for this road network was responsive patching and overlay. From these results it can be deducted that the existing trend of maintenance will give the road a lesser functional quality when compared to the scheduled application of overlay and patching.

Iran Embassy to Bisrate Gebriel

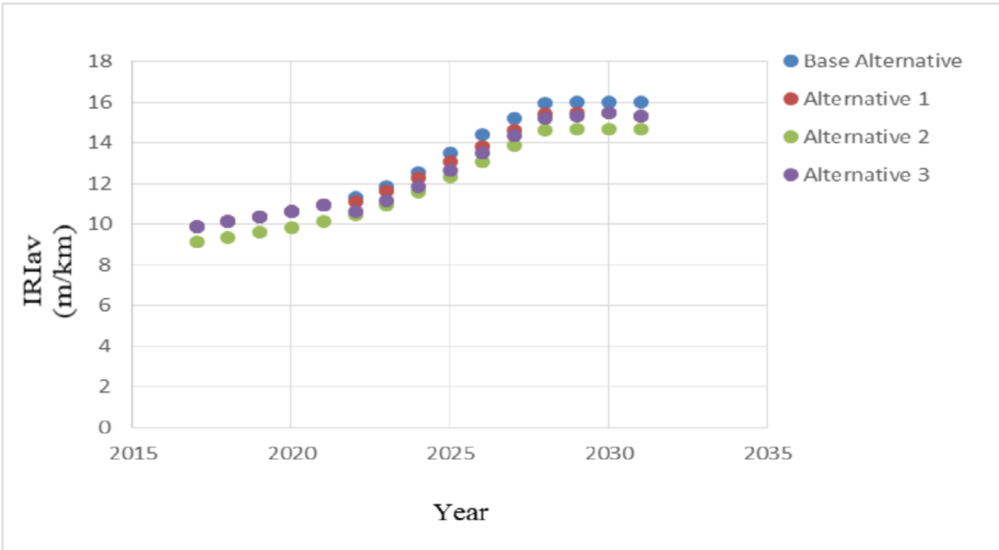

Figure 5: Roughness progression of different alternatives

In this case the results show that Alternative two has resulted in the lowest IRI value while Alternatives 1 and 3 show increased IRI values respectively. The base Alternative has shown the maximum IRI value: inferring that the existing maintenance alternative for this road network will leave the road into rough (uncomfortable) condition as time passes.

Bisrate Gebriel to Iran Embassy

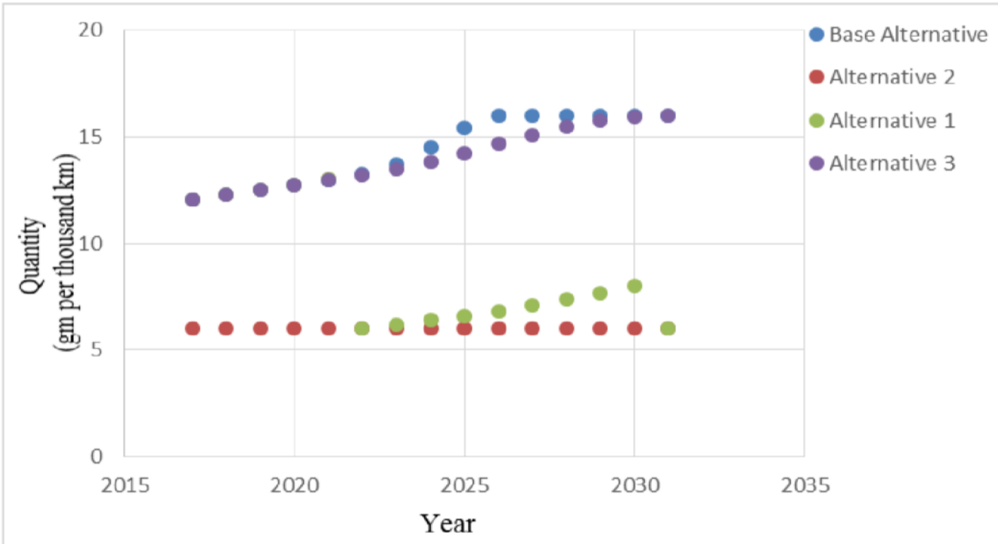

Figure 6: Roughness progression of different alternatives

According to Figure 6 it is Alternative 2 which has shown the least IRI value. The other Alternatives have shown an increasing IRI: which implies they will provide rougher road condition than Alternative 2.

The results generally has shown that the three alternatives show approximate values: Alternative 2 resulting in the lowest IRI progression. Alternative 3 and 1 has resulted in the next higher values of IRI values respectively.

4.3. Annual Emission

Gotera Interchange to Meskel Square

Section One

The report of annual emission by vehicle illustrates the emission of particles as the alternatives are varied. The type of pollutant particles included under the emission report are hydrocarbon

(HC), carbon monoxide (CO), nitrous oxide (NOx), sulphur dioxide (SO_2), carbon dioxide (CO_2), particulates (Par) an d lead (Pb). The annual emission by vehicles for different Alternatives is illustrated in Figure 7 below.

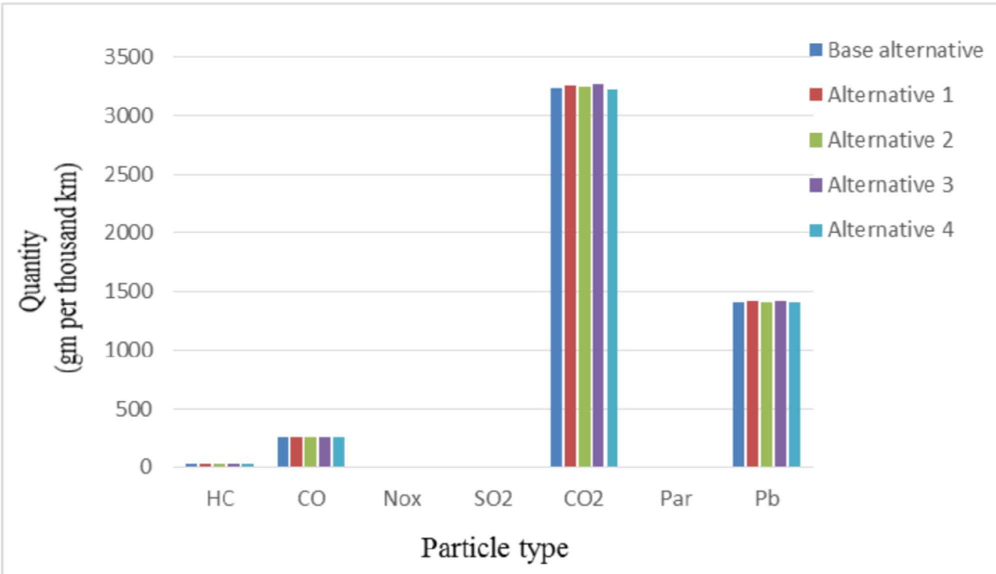

Figure 7: Annual Emission for different Alternatives

From the results it can be understood that the alternatives come up with close emission values. But relatively alternative 4 has resulted in minimum emission quantity: the base alternative having the second lower emission value. Alternatives 2, 1 and 3 has provided an increasing emission respectively. Thus Alternative 4 will result in less fuel consumption: which in turn release less pollutant gases when compared to the other alternatives.

Section two

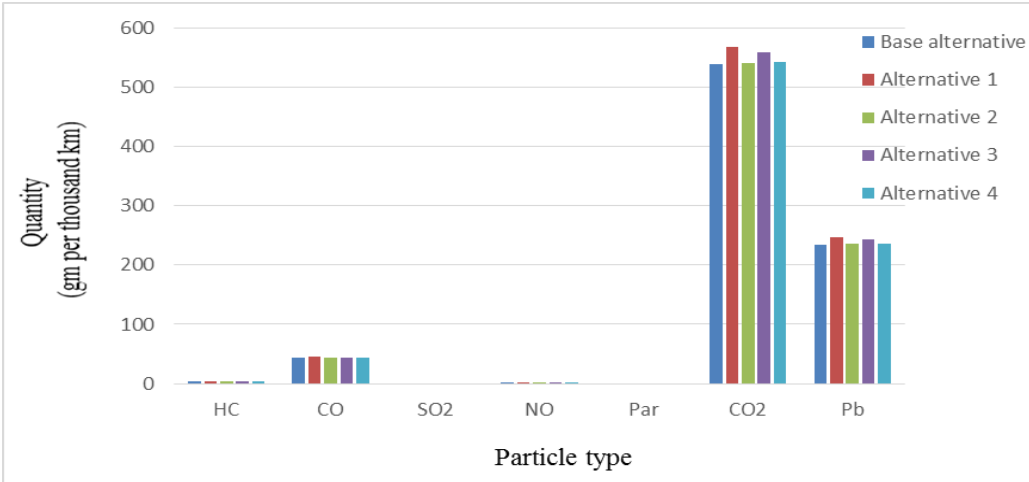

Figure 8: Annual Emission for different Alternatives

After the comparison of the alternatives, it has been found that alternatives 1 and 3 will produce high amount of pollutant gases if they are used as maintenance alternatives. Alternative 2, three and the base alternative have resulted in a relatively minimum value of emission: indicating a lower resultant fuel consumption.

Meskel Square to Gotera

Section one

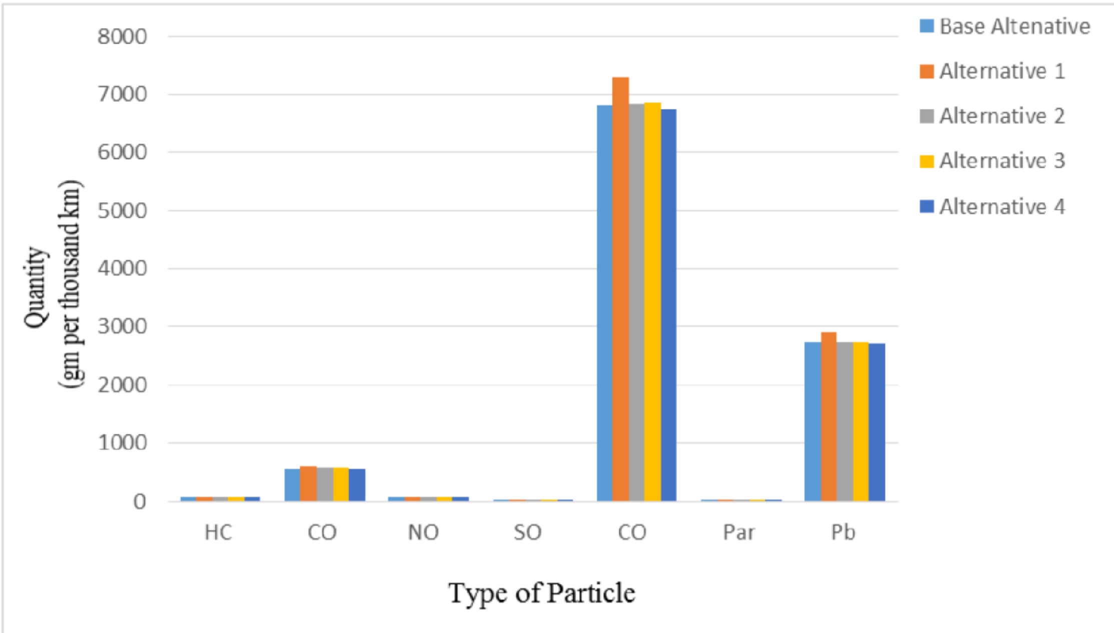

Figure 9: Annual Emission for different Alternatives

Similar to the results of the above sections Alternative 4 has resulted in the lowest emission quantity. As such the application of this maintenance alternative will keep the environment relatively safe.

Section two

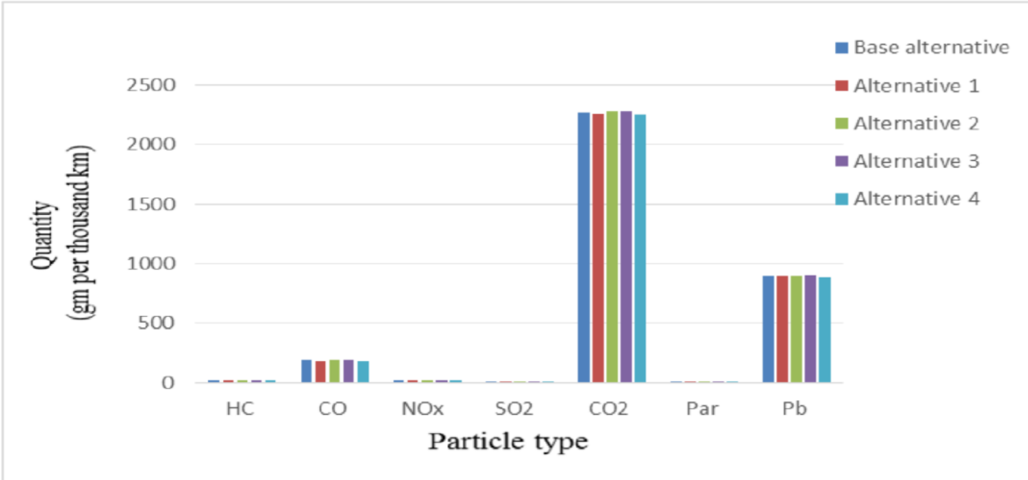

Figure 10: Annual Emission for different Alternatives

The analysis result for the above successive sections show that the alternatives 1 and 4 will give a relatively low amount of pollutant particles: Alternative 4 resulting in the lowest amount. The higher the emission quantity the more pollutant the alternative would be.

Generally the emission reports of HDM-4 for the sections in both directions under the network has shown that the alternatives had given approximate values. Accordingly, Alternative 4 has resulted in the lowest emission. This implies that the application of scheduled patching and overlay on the road network will produce the lowest pollutant particles. This indicates that the alternative will provide an environmental friendly condition.

Iran embassy to Bisrate Gebriel

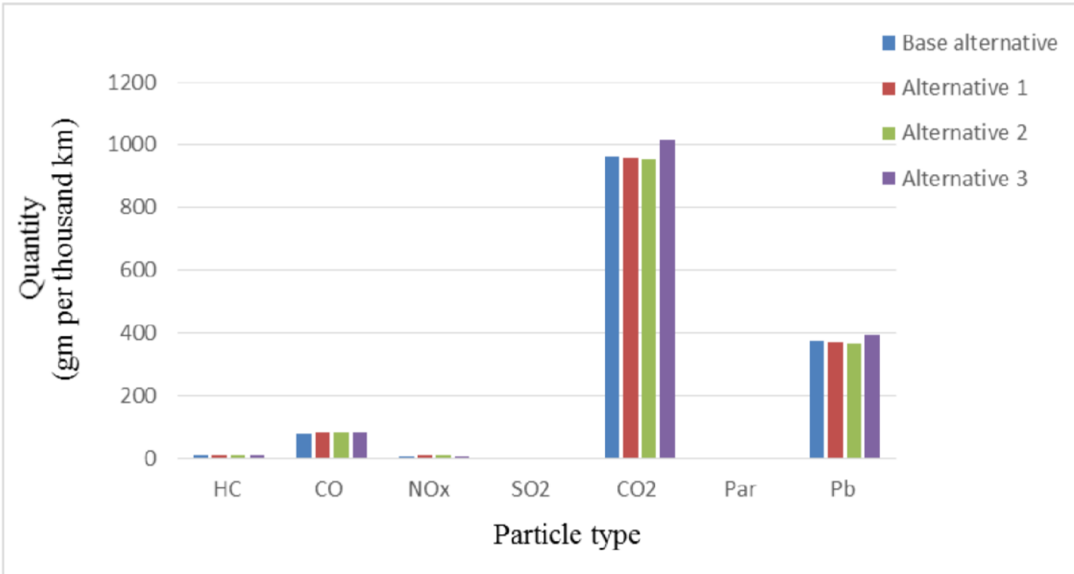

Figure 11: Annual Emission for different Alternatives

For this road network alternative 2 has resulted in the least emission quantity which means it will consume less fuel. Accordingly the application of scheduled overlay and patching will keep the environment relatively safe. Scheduled patching operation has shown the highest value; meaning that it will pollute the environment relatively in high quantity.

Bisrate Gebriel to Iran Embassy

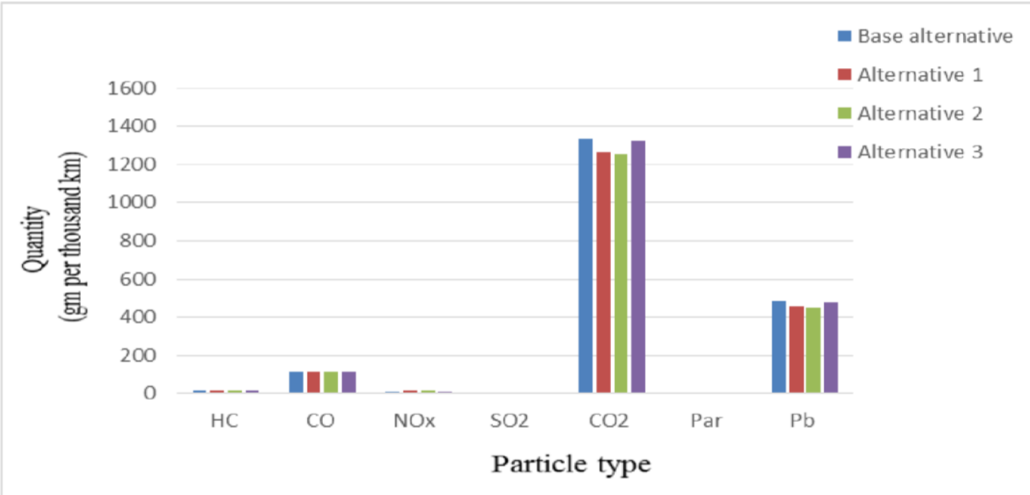

Figure 12: Annual Emission for different Alternatives

In this case the result shows that the alternatives 1 and 2 have resulted lower quantity of emission. The base alternative and alternative 3 has resulted in high amount. This implies that patching operation will result in the emission of high amount of pollutant particles.

Generally, for the sections in both directions under this network there is a varying value of emission for the different particulates. Therefore, decision should be made after a relative comparison between the different alternatives under consideration. Accordingly, alternatives 1 and 2become preferable since they show relatively lesser emission values.

4.4. Selection of Optimum Maintenance Alternative

The selection of the optimal method of maintenance under this study is undergone after the consideration of HDM-4 analysis reports of total discounted Net present Values, deterioration and vehicle emission. The alternative with high discounted Net Present Value, the lowest roughness progression and the lowest vehicle emission quantity have been considered as the optimal maintenance strategy for the road networks.

Gotera Interchange to Meskel Square

After comparing the reports of HDM-4 alternative four, Scheduled patching, is found to be the optimal maintenance technique. It has resulted in high positive NPV values for the three sections and a lower negative NPV for one section with only three segments. But the overall result shows that this alternative is relatively with high value of NPV. This indicates that this alternative is profitable if applied. The deterioration report shows that this alternative has provided a lower roughness progress: providing a functional quality for the road network. From emission by vehicle report it has been understood that alternative four has resulted in the lowest emission value. Therefore scheduled patching and overlay is finally taken as the optimal maintenance technique for both directions of the road network from Gotera Interchange to Meskel Square.

Iran Embassy to Bisrate Gebriel

For this road network the highest NPV was resulted by Alternative two: scheduled Overlay and patching. The roughness progression for this alternative is found to be lower: which indicates a comfortable riding condition. The overall emission by vehicle for this alternative also has resulted in a lower value. Therefore the application of scheduled patching and overlay is found to be profitable, environmentally safe and functional.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

This study finally derives the following conclusions:

- The dominant types of distresses that were available on the road network under the study have been found to include raveling, pothole formation and rutting.
- The analysis results of HDM-4 have shown that there is a significant difference between the annual discounted net present values of the assigned maintenance alternatives.
- The assigned maintenance alternatives have resulted in close Roughness progression and emission quantities.
- The annual discounted net present value of the existing routine maintenance technique has resulted in a zero value which indicates that it is not a cost-effective to use this approach.
- The emission by vehicle report of HDM-4 shows that there is no substantial difference between emission quantities of other alternatives assigned under the study.
- The roughness progression for the existing maintenance technique show varying trends for different sections.
- Based on the analysis results of HDM-4, the optimal maintenance technique for both directions of the road networks from Gotera Interchange to Meskel Square and from Iran Embassy to Bisrate Gebriel has been found to be the application of scheduled patching and overlay.
- Thin lays can be used as maintenance alternative for road sections which are not severely damaged, i.e. they can be taken as a maintenance alternative for the road network from Iran Embassy to Bisrate Gebriel.

5.2. Recommendations

The following recommendations were put forward after the results of this study.

- The government should give concern to maintenance techniques other than routine maintenance trends.
- A scientific way of prioritizing maintenance alternatives should be taken into consideration.
- Proper and detailed documentation trends should be developed since input data are basic instruments to come up with the optimal maintenance technique.
- Condition survey data should be done in a scientific way in order to recognize the extent and severity of distresses at a relatively accurate level.

5.3. Future Research Directions

- Since there is no fixed reference for the maintenance of roads, the establishment of pavement maintenance standard for Ethiopia will create uniform maintenance trends throughout the country.

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Annex 1: Sample Worksheet of Distress Data

				ADDIS ABABA CITY ROADS AUTORITY								
				CENTRAL ADDIS ABABA ROAD ASSET MANAGEMENT DIRECTORATE								
				ANALYSED MAINTENANCE INSPECTION								
Item No.	Route number	Road class	Road Number	Road Name	section	Distress Type				Maintenance Type		Remark
						pothole	failed	Raviling	corocodile	Patching area	Overlay area	
1	P003	PAS	105	From Meskel Sq to Gotera inter-change	3			190			190.00	
2	P003	PAS	105	From Meskel Sq to Gotera inter-change	1			45			45.00	
3	P010	PAS	180	From Gofa Mazoria toTelecomunication Building Kikos Junction	2			1300	665		1,965.00	
4	P010	PAS	180	From Gofa Mazoria toTelecomunication Building Kikos Junction	3			400	300		700.00	
5	P008	PAS	6	From Anbasader theater to Zewditu	1			1500			1,500.00	
6	P008	PAS	6.1	From Zewditu to Sheraton Hotel	1			2500	250		2,750.00	
7	P306	PAS	7	From Filwha hotel to Zewditu Hospital	3	36		800		36.00	800.00	
8	P302	PAS	94	From 6th Police Station to 93.1 Road	4			400			400.00	
9	P309	PAS	184	From Mexico beside Federal Inland revenue to Orbis Jun.	1	61		3000		61.00	3,000.00	
10	P318	PAS	111	From Gotera inter change to Wolo Sefer	2	10		1000		10.00	1,000.00	
12	S006	SAS	95	From total to Adewa (Sigenal)	1			3080			3,080.00	
13	S201	SAS	106	From Meshualekia to Flamengo	1	50		3500		50.00	3,500.00	
14	S202	SAS	107	From Lancha to Esrahele Garaje	1			3500			3,500.00	
16	CS046	CS	46C	From Dan techno office through road no. 108 to Bole Printing Junction		60	8400			60.00	8,400.00	

Annex 2: Interview Questions

1. How are maintenance programs done in Addis Ababa City Roads Authority, are they responsive or properly scheduled?

2. What types of maintenance trends are experienced?
3. Are these maintenance techniques scientifically selected?
4. Does the Authority check the effectiveness of the existing maintenance techniques?

Biography of the Author

The Author of this study, Betelihem Alemu Berta is a Bachelor Degree graduate of Civil Engineering from Addis Ababa Institute of Technology in 2016. I have an a one year and four months experience as a site supervisor in a building consulting firm, Birhan Tegegn Architectural and Civil Engineering Consultants. I have also worked as an evaluator of completed building constructions in Construction Solutions Company. I am certified in short term courses that support my field of study: including AUTOCAD, SAP, Entrepreneurship and Leadership Trainings.